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WATER RECLAMATION STUDY PROGRAM

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PROGRESS REPORT

WATER RECLAMATION STUDY PROGRAM

DEMONSTRATION PROJECT GRANT

NO. WPD-21-03

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Covering the Period

July 17, 1964 to September 14, 1965

October, 1965

WATER RECLAMATION STUDY PROGRAM

Demonstration Project Grant

No. WPD-21-03

SUMMARY

A satisfactory operating regime has been established for the Chicago Pump Co. "Rapid-Bloc" activated sludge system. The control parameter in the operation of this unit is the Solids Retention Time (SRT). Data have been accumulated to demonstrate that an efficiency of treatment of 80-95 percent for BOD removal and 75-90 percent for suspended solids removal can be obtained on a continuous basis when SRT of about 13 days is maintained. It has been possible to obtain this high operating efficiency with an aeration period of four hours and a settling period of 2 hours, as opposed to conventional aeration and settling periods of 6-7.5 hours and 2-4 hours, respectively.

Approximately one million gallons of activated sludge effluent have been processed by means of the coagulation-settling-filtration treatment sequence, with alum as the coagulant, using Infilco, Inc. chemical treatment and sand filtration equipment. Effluent phosphorous concentrations as low as 0.5 mg/l were obtained, with phosphorous removal efficiencies of 78-93 percent. Rather large dosages of alum (372-391 ppm) were required. Difficulties involving the formation of "mud-balls" in the sand filter were encountered and the necessity for insuring adequate settling prior to applying the chemical treatment effluent to the sand filter became apparent.

Approximately 500,000 gallons of activated sludge effluent have been treated by means of the filtration-ion exchange flow sequence, with both sand and diatomite filtration being tried. Less than optimum treatment effectiveness was observed, and this is attributed primarily to filtration difficulties. The fouled condition of the sand filter caused by the problems which developed during chemical treatment reduced the filtration efficiency of the sand filter significantly. It was also discovered that a diatomite filter flow rate of 10 gpm could not be maintained for a 12-hour period, as was originally hoped. As a consequence of these difficulties the ion exchange column did not receive the quality of influent water which was anticipated. Nevertheless, even under undesirable operating conditions, ion exchange treatment was able to produce an effluent water with a phosphorous content of 0.8-2.5 mg/l, which was a reduction of 66-88.5 percent for this key nutrient element. Techniques for resin restoration on a pilot scale were formulated and tested and appeared satisfactory.

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STATEMENT OF PROGRESS

INTRODUCTION

It has long been recognized that "complete" sewage treatment by conventional methods has little or no effect upon dissolved inorganic materials, such as chloride and phosphorous. It has also become apparent that certain "refractory" constituents of domestic wastewaters (such as alkylbenzenesulfonate) are not entirely removed or stablized by the usual methods of sewage treatment. Up until the present generation, it has usually been sufficient to stabilize the readily-decomposable organic materials in wastewater enough to prevent serious oxygen depletion in receiving streams, lakes, or other bodies of water.

In the modern age, the creation and use of a multitude of new materials has combined with rapid population growth to create heretofore unknown problems of both water quality and water quantity. Record quantities of water are being used to transport both the former "normal" sewage-type wastes and also the new "refractory" materials resulting from modern technology. At the same time, demands are great for potable and industrially-usable water to keep pace with our rapidly expanding population. In this situation, present problems clearly indicate the limitations and potentially critical future inadequacy of even "complete" sewage treatment, as we know it today.

Possibly two of the most obvious examples which point up the problem are the presence of refractory "new" materials in our tap water, such as synthetic detergents and unknown organics identified only by the CCE test, and the increase of the amount of eutrophic inorganic materials such as phosphorous and nitrogen in raw water supplies. In certain areas tapwater drawn into a drinking glass may foam so vigorously as to produce a "head" on the glass of drinking water. This is due to refractory ABS

material and is esthetically objectionable, at the very least. Likewise, increasing amounts of phosphate, nitrate and other "trace" nutrients have been associated with the increasing frequency of algal "blooms" in large rivers, lakes, and reservoirs. These can cause serious water treatment difficulties, occasionally to the point of rendering the waters unfit for use even after processing in existing water treatment plants.

WATER RECLAMATION STUDY PROGRAM

The initial objective of the Stanford Water Reclamation Project was to investigate the potential of various tertiary and advanced treatment techniques for further treating activated sludge effluent water in order to keep pace with the problems presented by the increasingly more complex and rigorous makeup of domestic wastewater. Inasmuch as algae blooms and the buildup of organic refractory materials appear to be two of the most pressing problems at present, emphasis was placed upon the removal of key inorganic "nutrient" materials, as well as reduction of COD and ABS content of activated sludge treatment effluent.

This project is uniquely applicable to the existing situation at Stanford University. The school is short of water due partially to inadequate surface storage and to the low groundwater level under the 8,800-acre campus. An ample supply of treated sewage is available at the nearby Palo Alto Sewage Treatment Plant. It was felt that if a satisfactory and economical method of producing a high-quality water could be developed, reclaimed water could be pumped to Lake Lagunita on campus and used for recharge of groundwater supplies, irrigation, and recreational uses. The reclaimed water would have to be of a quality which approached drinking water standards, and would have to have phosphorous or nitrogen concentrations low enough to preclude or limit the growth of algae in the lake.

A three phase program was outlined. The first phase consisted of laboratory studies of various tertiary and advanced waste treatment techniques to determine the most suitable method of reclaiming the wastewater. The initial exploratory investigation was supported by Demonstration Project Grant No. WPD-21-01 from the U. S. Public Health Service and covered the period from September 15, 1962 through July 15, 1963. It was found

that both ion exchange and chemical precipitation processes could deliver the desired quality water. A report was submitted and a second grant (No. WPD-21-02) was received from the Public Health Service covering the period from July 16, 1963 through July 15, 1964. During this period the ion exchange and chemical treatment techniques were both studied intensively on a laboratory scale. Control parameters and performance characteristics were determined so that predictions of larger-scale treatment feasibility and effectiveness could be made. Considerable attention was given to the development of methods for resin regeneration and the restoration of spent or exhausted resin capacity. A report was submitted and a third demonstration grant (No. WPD-21-03) was obtained, covering the period from July 16, 1964 through September 15, 1965. During this period the first phase (the laboratory evaluation) of the project was concluded, and a report submitted.

This present report covers the initial stages of the second phase of the project, which is the confirmation of the laboratory work through the operation of a 10 gpm pilot plant located at the Palo Alto Sewage Treatment Plant.

PILOT PLANT PROGRAM

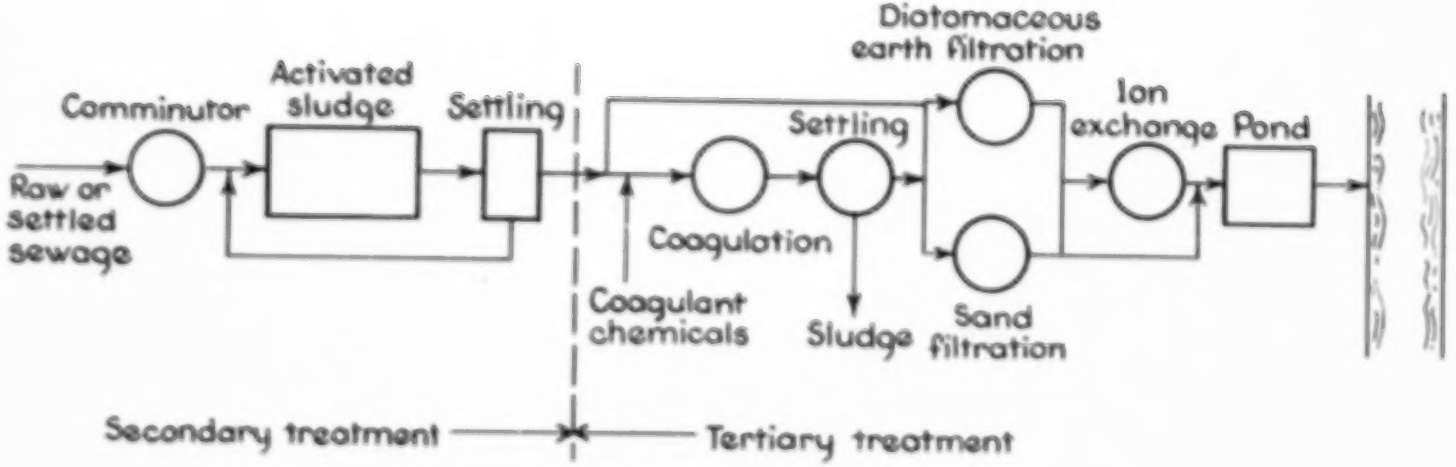
The flow sheet of the 10 gpm pilot plant is shown in Figure 1. The pilot plant is designed to utilize two basic flow sequences, both of which include high-rate activated sludge treatment as the initial step. Flow sheet No. 1 consists of high-rate activated sludge treatment, chemical coagulation and settling, sand filtration, and discharge to a pond. Flow sheet No. 2 utilizes activated sludge treatment followed by either sand or diatomite filtration, an ion exchange column, and discharge to the effluent pond.

Activated Sludge Unit

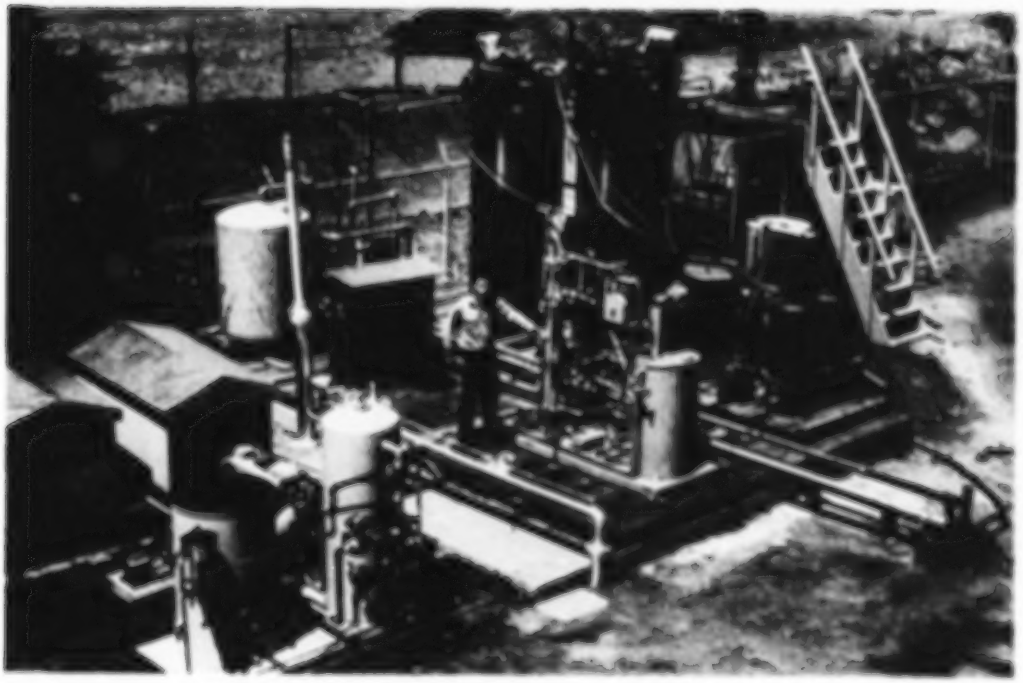
The activated sludge unit is a pre-assembled "Rapid-Bloc" type unit, provided by the Chicago Pump Co., Hydrodynamics Division, FMC Corporation. The unit consists of an aeration chamber, a settling tank, and an aerobic digestion compartment. It is operated as a high-rate secondary treatment unit, with an overall (aeration tank plus settling tank) theoretical detention time of 5.9 hours at the 10 gpm flow rate. The aerobic digestion compartment capacity is 295 cubic feet. A comminutor is included, although the unit normally receives settled sewage (i.e., the effluent from the Palo Alto primary settling tanks) as the influent liquid.

Chemical Treatment

The chemical treatment unit was provided by the Infilco Division of the Fuller Company. It is essentially a water softening unit with a combination mixing-coagulation-settling tank (Densator) and a recarbonation tank. Any combination of chemicals can be automatically fed to the Densator by means of self-adjusting conductivity cell feed controllers.



Flow Diagram of Pilot Plant
Fig. 1



STANFORD PILOT PLANT
FIG. 2

Sand Filter

The sand filter was also provided by the Infilco Company. It is a pressure-type filter with a surface area of 9.62 square feet, and utilizes a 24-inch depth of water-plant grade filter sand.

Diatomaceous Earth Filter

The diatomaceous earth filter has been provided by the Filtration Systems Division of De Laval Turbine, Inc. The unit has a total filter septum area of 5.5 square feet, and utilizes a compressed air "bump" type of backwash.

Ion Exchange Column

The ion exchange column was provided by the Infilco Co., also. It is operated at a resin capacity of eight cubic feet. The column is two feet in diameter.

Ion Exchange Resin

Duolite A-102D, a strong base type of resin, was donated by the Diamond Alkali Company. This was selected as the most effective resin on the basis of the laboratory work, in which a number of types and varieties of ion exchange resins were tested.

Pond

The pond has a capacity of approximately 250,000 gallons. The principal purpose of the pond is to prove and demonstrate under actual conditions that the growth of algae can be prevented or drastically inhibited by removal of inorganic nutrient materials from sewage treatment plant effluents. It also will be used to provide information concerning the bacterial and virus population in a pond receiving reclaimed water.

PLANT OPERATION

Activated Sludge

Satisfactory operation of this unit has been achieved with the Solids Retention Time (SRT) being the chief control parameter. Mixed liquor solids have been maintained at the 5000 mg/l level, with a resulting SRT of about 13 days. Theoretical average detention times have been 4 hours and 2 hours for the aeration tank and the settling tank, respectively. This unit utilizes a gravity-type sludge return and it was found desirable to clear the return chimneys daily, which requires approximately 10 minutes.

Chemical Treatment

The chemical treatment unit has been operated with both lime and alum as the coagulant chemical. When lime was used the unit operated as originally designed, so that lime addition, mixing, and settling took place in the Densator tank, with the second tank being used for recarbonation. When alum was used, the second tank was used to provide an additional settling period, since recarbonation was not required.

Sand Filter

The sand filter is operated at a flow rate of about 1.04 gpm per square foot. Two pumps are available for backwashing, with pumping capacities of 125 gpm and 185 gpm. The maximum volume of water which can be stored and used for backwashing is about 1,400 gallons. The sand filter has been used with both the chemical treatment flow sheet and the ion exchange flow sheet.

Diatomite Filter

The diatomaceous earth filter is operated at a flow rate of 1.82 gpm per square foot of filter area. The unit is pre-coated with a three-eighths inch thick layer of diatomite which is increased to a total thickness of one and one-eighth inch during the run by the body feed. The diatomite filter has been used in the ion exchange flow sheet only.

Ion Exchange Column

The ion exchange column is operated at a flow rate of 60 bed volumes (B.V.) per minute. The unit has been regnerated with a 10 percent brine solution after each 250-300 bed volumes, normally.

RESULTS

The unique nature of this pilot plant and the scarcity of published data pertinent to the use of water treatment techniques and processes for treatment of sewage effluents made it advisable for the unit sizes and operating techniques to be based to a large extent upon standard practice and best estimates and predictions of equipment manufacturers. By and large the original equipment performance expectations have been realized. However, the obvious interdependence of the process unit efficiencies required that a fairly specific performance evaluation be made for each individual unit, in order to be able to operate the whole system at its optimum condition and thus obtain a fair and accurate evaluation of the overall feasibility of the two methods of treatment being tested. The emphasis to date therefore has been on the optimization of the pilot plant operation, including modification of the individual treatment components where necessary. A significant amount of data relative to the overall performance of each flow sheet has been gathered, much of it under less than optimum operating conditions. It is therefore felt that the results achieved to date are probably an extremely conservative indication of the potential benefits inherent in the proposed methods of treatment. This is particularly true with regard to the ion exchange flow sheet.

Activated Sludge

A satisfactory operating regime has been established for the "Rapid-Bloc" activated sludge unit, using the Solids Retention Time as the major control parameter. As can be seen from Table I,

TABLE I

AERATION TANK DATA

Date 1965	Pound of BOD per Day per Thousand Cubic Feet	Mixed Liquor Suspended Solids (mg/l)	Solids Retention Time (days)
1/5		4020	10.7
1/12	47.6	5140	22.5
1/18	63.5	4230	13.6
1/25	57.4	5360	12.8
2/2	65.0	5540	12.0
2/8	30.6	6180	9.2
2/15	69.6	4900	7.3
2/23	47.8	5180	16.0
3/1	56.2	5080	10.0
3/8	60.9	3720	15.6
3/22	46.3	5280	14.6
4/3	52.4	6440	20.0
Average	54.3	5090 mg/l	13.7 days

the unit has been loaded fairly heavily, at a rate of about 54 pounds of 5-day BOD per 1000 cubic feet of aeration capacity. The high mixed liquor suspended solids concentration (5100 mg/l) was required in order to obtain an SRT of 13.7 days. It may be seen from Table II that the plant operating efficiency has been superior to that achieved in "conventional" secondary treatment utilizing considerable longer detention times (overall detention times of 7-10 hours versus the "Rapid-Bloc" detention time of 6 hours). It should be borne in mind that the efficiencies shown in Table II are for the secondary portion of the treatment process only. The results obtained indicate the superiority of the SRT as the design and control parameter over older and more empirical standards. Table III further illustrates the operational improvement which accrues on increasing the SRT. The increase in the SRT shown in Table III was obtained chiefly by improved plant maintenance and closer control, in addition to some minor structural changes.

Analyses and comparisons were made to determine whether the normal activated sludge effluent produced on a continuous basis was any different from the effluent used in the laboratory during the initial feasibility testing. Table IV indicates the make-up of the actual plant effluent compared with the laboratory influent with respect to the most significant ions and refractory-type materials. It is evident that the activated sludge plant effluent has basically the same make-up as the laboratory test feed water.

Chemical Treatment

The efficiency of phosphate removal by chemical precipitation utilizing alum as the coagulant was evaluated over a three month period.

Approximately one million gallons of activated sludge effluent were processed with alum dosage varying from 198 mg/l to 397 mg/l.

TABLE II

ACTIVATED SLUDGE TREATMENT EFFICIENCY

Date 1965	BOD Inf. (mg/l)	BOD Effl. (mg/l)	BOD Reduction (%)	SUSPENDED SOLIDS Infl. (mg/l)	SUSPENDED SOLIDS Effl. (mg/l)	SUSPENDED SOLIDS Reduction (%)
1/12	122	10	92	78	17	78
1/18	166	35	79	116	30	74
1/25	150	18	88	92	24	74
2/2	170	25	85	108	32	70
2/8	80	9	89	108	22	80
2/15	182	29	84	100	21	79
2/23	125	14	89	124	25	80
3/1	147	19	87	86	18	79
3/8	159	27	83	104	22	79
3/22	121	21	82	100	32	68
4/3	137	11	92	112	15	87
Average	142	20	86	102	23	77

TABLE III

ACTIVATED SLUDGE EFFLUENT

	September - December 1964			January - July 1965		
	Avg.	Max.	Min.	Avg.	Max.	Min.
BOD (mg/l)	25	80	7	19	35	7
Suspended Solids (mg/l)	27	90	5	25	47	13
Nitrate (mg/l as N)	15.7	19.5	12.3	14.8	28.9	1.5
Mixed Liquor Suspended Solids (mg/l)	4230	6420	1880	5090	6440	3720
Average Solids Retention Time		10.9 days			13.7 days	

TABLE IV

	Feed Water for Laboratory Ion Exchange Test			Activated Sludge Effluent 12/1/65 - 1/7/65		
	Avg.	Max.	Min.	Avg.	Max.	Min.
Phosphorous (mg/l as P)	8.0	9.0	7.4	7.0	10.4	5.5
Nitrate (mg/l as N)	13.5	18.7	6.8	14.8	28.9	1.5
Nitrate (mg/l as N)	0.61	1.06	0.30	0.19	0.45	0.05
COD (mg/l)	35	37	33	53	86	27
ABS (mg/l)	1.8	2.2	1.1	1.5	2.1	0.7
Color (units)	43	65	32	41	80	25

Typical results are shown in Table V. It can be seen that optimum results were obtained at about a 375 ppm alum dosage.

Table VI indicates the results of four separate treatment runs, and includes the reduction produced by the settling tank and the sand filter through the removal of the unsettled phosphate-containing floc. The settling tank referred to is the chemical treatment plant recarbonation tank. It can be seen that at times a significant amount of material was removed in this intermediate settling tank. This infers that when alum is used some sort of intermediate settling is required after Densator treatment, in order to prevent serious over-loading of the sand filter. Even when the settling tank was in use, there was at times a considerable carry-over of particulate material to the filter, even though the plant was operated at a constant flow rate. This is a significant finding, since it became apparent during the latter part of the chemical coagulation testing phase that removal of chemical coagulation floc by sand filtration can produce problems, if backwash conditions and procedures are not optimized.

Mud balls were found in the filter after 2 months of use with the coagulation unit; these were apparently due to improper or too infrequent backwashing when the sand filter was operated in the chemical treatment flow sheet. It is therefore considered that the true effect of the sand filter in the chemical coagulation flow sheet has yet to be satisfactorily determined.

In summary, the pilot plant work has indicated that, based on the alum dosages, and the previously determined line costs (Table VII), phosphate removal by coagulation appears to be relatively expensive, although a high degree of phosphate removal can be obtained.

TABLE V

WATER QUALITY AFTER COAGULATION AND SETTLING

Alum Feed Rate mg/l	Phosphorus Avg. Eff. mg/l	Phosphorus Avg. % Red.	SS Avg. mg/l	SS % Red.	COD Avg. Eff. mg/l	COD % Red.
391	0.5	91	13	53	34	47
372	0.47	93	10	-100*	18	67
357	0.93	87	6.5	55	48	25
298	1.24	78	23	-9*	29	35
198	1.7	79	6	-100*	16	-

* Indicates an increase of suspended solids.

TABLE VI

Date 1965	Activated Sludge Effluent	Densator Effluent		Settler Effluent		Sand Filter Effluent		Alum Dosage
0700/ April 13	(mg/l)	(mg/l)	Overall % Reduction	(mg/l)	Overall % Reduction	(mg/l)	Overall % Reduction	
Phosphorous	5.4	1.8	67	1.7	68.5	0.84	84.5	
SS	4	5	+20	5	+20	2	50	198mg/l
COD	35	30	14	25	28.5	25	28.5	
1125/ April 30								
Phosphorous	6.9	1.9	72.5	0.3	95.5	0.28	96	
SS	26	46	+77	19	27	4	84.5	298mg/l
COD	44	23	47.5	14	68	10	77	
1600/ May 12								
Phosphorous	7.7	5.5	28.5	4.4	43	1.2	84.5	
SS	25	66	+165	60	+140	16	36	298mg/l
COD	68	63	8	68	0	40	59	
1300/ June 21								
Phosphorous	14.5	-	-	1.6	89	0.5	96.5	
SS	27	-	-	6	78	5	81.5	397mg/l
COD	54	-	-	21	61	17	68.5	

TABLE VII

CHEMICAL TREATMENT

Date 1964	Phosphates as P, mg/l Inf.	Dens.	Recarb.	% Rem.	Lime Used lbs/1000 gal.	Mg/l
Sept. 9	9.3	0.12	0.095	99	3.57	428
Sept. 10	6.2	0.08	0.08	99	3.57	428
Sept. 11	10.0	0.095	5.6	44	3.57	428
Sept. 13	8.8	0.13	2.4	73	3.57	428
Sept. 14	7.1	0.01	0.0	99	3.57	428
Sept. 15	8.0	0.02	0.05	99	3.57	428
Sept. 16	10.5	0.01	0.15	99	3.57	428
Sept. 17	9.2	0.025	0.3	97	3.57	428
Sept. 18	4.7	0.025	0.13	97	3.57	428

TABLE VIII

SAND FILTER BACKWASH RECORD

(Sand Filter Used With Chemical Treatment Flow Sheet)

Date 1965	Gallons of Chemical Treatment Effluent Processed	Filter Run Time in Days
May 3	57,500 gallons	4
May 5	28,800 gallons	2
May 13	86,000 gallons	6
May 18	57,500 gallons	4
May 25	72,000 gallons	5
May 28	43,000 gallons	3
June 4	29,000 gallons	2
June 7	42,600 gallons	3
June 10	42,800 gallons	3
June 25	43,100 gallons	3
Average	50,230 gallons	3.5 days

Filtration

Table IX and Table X indicate the filtration performance of both types of filtration when the applied liquid is activated sludge effluent. Examination of Table IX reveals that an essentially solids-free effluent water can be produced by diatomite filtration regardless of any reasonable fluctuation in the applied liquid quality. It can be seen that water with zero suspended solids was produced even when the influent liquid contained as much as 72 mg/l of suspended solids. (The slightly poorer effluent quality obtained during Run No. 1 is attributed to operating difficulties of a mechanical nature.) Table IX indicates that diatomite filtration ought to provide an excellent quality water for processing in the ion exchange column. Unfortunately, the diatomite filter at the Pilot Plant is of rather small capacity and will not operate over a 6 to 12 hour period without being backwashed and re-coated. Since the pilot plant operating routine requires that the filtration process and ion exchange column function continuously over the fifteen-hour period each day when the plant is unattended, it is obvious that the present diatomite filter cannot be used exclusively. Efforts are being made at present to replace the present diatomite filter with another diatomite unit with either greater capacity, or provision for automatic backwashing.

In the present situation, then, it is necessary to utilize the sand filter at least part of the time in order to accumulate a meaningful amount of data regarding the efficiency of the ion exchange unit. Table X presents typical results obtainable from sand filtration of activated sludge effluent. Although a significant and often striking reduction of suspened solids can apparently be assured using the sand filter, an additional and possibly troublesome factor is involved in the sand filter operation, which is not indicated by Table X.

TABLE IX

EFFICIENCY OF DIATOMITE FILTER
PROCESSING ACTIVATED SLUDGE EFFLUENT

	Hours in Operation	Suspended Solids (mg/l) Influent	Effluent	Gallons Filtered
Run No. 1	0.5	11	3	150
	1.0	10	4	450
	1.5	9	1	750
	2.0	8	3	1050
	2.5	12	2	1350
	3	11	2	1650
	3.5	14	3	1950
		11 mg/l avg.	2.6 mg/l avg.	
Run No. 2	0.5	5	3	300
	2	5	0	1200
	2.5	3	0	1500
	3	4	0	1800
	3.75	31	0	2250
	4.25	45	1	2550
		15.5 mg/l avg.	0.7 mg/l avg.	
Run No. 3	0.25	6	0	150
	1	7	0	600
	2.25	72	0	1350
	2.75	13	0	1650
	3.25	6	0	1950
	3.75	7	0	2250
		18.5 mg/l avg.	0 mg/l avg.	

TABLE X

EFFICIENCY OF SAND FILTER PROCESSING
ACTIVATED SLUDGE EFFLUENT

	Hours in Operation	Suspended Solids (mg/l) Influent	Effluent	Gallons Filtered
Run No. 1	0.5	156	8	300
	1.5	176	6	900
	2.5	24	3	1,500
	3.5	18	4	2,100
	4.5	26	4	2,700
	19.5	16	4	11,700
	21.5	18	4	12,900
	23.5	86	5	14,100
	25.5	34	2	15,300
	27.5	120	6	16,500
	29.5	38	4	17,700
	45.5	92	8	27,300
		67 mg/l avg.	5 mg/l avg.	
Run No. 2	0.5	34	11	300
	1.5	34	11	900
	2.5	38	11	1,500
	3.5	40	11	2,100
	4.5	40	10	2,700
	19.5	28	5	11,700
	21.5	48	7	12,900
	23.5	24	6	14,100
	25.5	10	4	15,300
	27.5	60	25	16,500
	45.5	34	7	27,300
		36 mg/l avg.	10 mg/l avg.	

It has been noted that when the sand filter is used for filtration of activated sludge effluent, small chunks or balls of a black, non-greasy substance are formed. This foreign substance is readily backwashed from the filter so long as the particles are small. However, when this particulate matter agglomerates, as it tends to do, it apparently incorporates sufficient sand particles into the increased mass that a piece of material is formed which, while definitely lighter than the sand particles, is only slightly lighter. When this situation occurs, it has been found that removal of the large particles by upflow backwashing is extremely difficult, even with very high backflow rates. Rise rates as great as 43 inches per minute have been found to leave a noticeable number of "black balls" on the sand surface after backwash was stopped.

No surface wash device is provided in the filter, so other means of attack had to be attempted. Backwashing with a high chlorine content water and also the use of a period of exposure of the filter bed to a high (200-300 ppm) chlorine concentration for periods up to 12 hours after filtration have not been effective in breaking down or disintegrating the "black balls" once they have formed. The test filter runs have been extremely long (Table X), and the applied activated sludge effluent was not chlorinated, so that it is possible that the use of more frequent backwashing or chlorination of the effluent prior to applying it to the filter may reduce or eliminate this problem.

In considering the reported performance of the ion exchange column, then, it should be kept in mind that continuously desirable pre-filtration has probably not been achieved, to date. Adjustments are being made to avoid or minimize these difficulties in the future, as well as to analyze and investigate more completely the pertienent aspects of filtration of activated sludge effluent. An attempt is being made to interest filter companies in the installation of new sand filters, which would be especially designed to handle activated sludge effluent.

Ion Exchange Treatment

The efficiency of treatment for the first 500,000 gallons of activated sludge effluent which was processed is summarized by Table XI and Figures 3, 4, and 5. An average phosphorous reduction of 70.5 percent and an ABS reduction of 78 percent were obtained. COD was reduced by 29 percent. The performance pattern for phosphorous removal in terms of the cumulative number of bed-volumes processed is indicated by Figure 6 and Figure 7. It is probable that a considerable portion of the decline in treatment effectiveness indicated by Figure 6 and Figure 7 was caused by the previously described operating difficulties involving pre-filtration. However, the effluent quality and overall performance obtained even during the latter part of this initial operating run was fairly good (an average effluent phosphorous content of 2.55 mg/l and a phosphorous removal efficiency of 66 percent). Efficiency of removal of ABS and COD was not reduced to any appreciable degree during the initial run, with about 75 percent of the ABS and one-third of the COD being removed at all times. Carbon filter adsorption samples were collected and analyzed by personnel of the California Department of Public Health after a total volume of about 415,000 gallons of activated sludge effluent had been treated. The following is a summary of their analytical results:

> "The activated sludge effluent, after passing through the pressure sand filter, contained slightly larger concentrations of Carbon Chloroform Extractables and slightly smaller concentrations of Carbon Alcohol Extractables. The results indicate that at the time of sampling the activated sludge effluent may have been picking up some CCE in the form of water solubles and strong acids from material which had previously been trapped in the sand filter.

TABLE XI

ION EXCHANGE TREATMENT

INITIAL 500,000 GALLONS OF WATER PROCESSED

	Phosphorus	ABS	COD	Chlorides
Average Influent (mg/l)	8.26	3.9	31	227
Average Effluent (mg/l)	2.45	0.85	22	328
Percent Reduction	70.5%	78%	29%	+44%

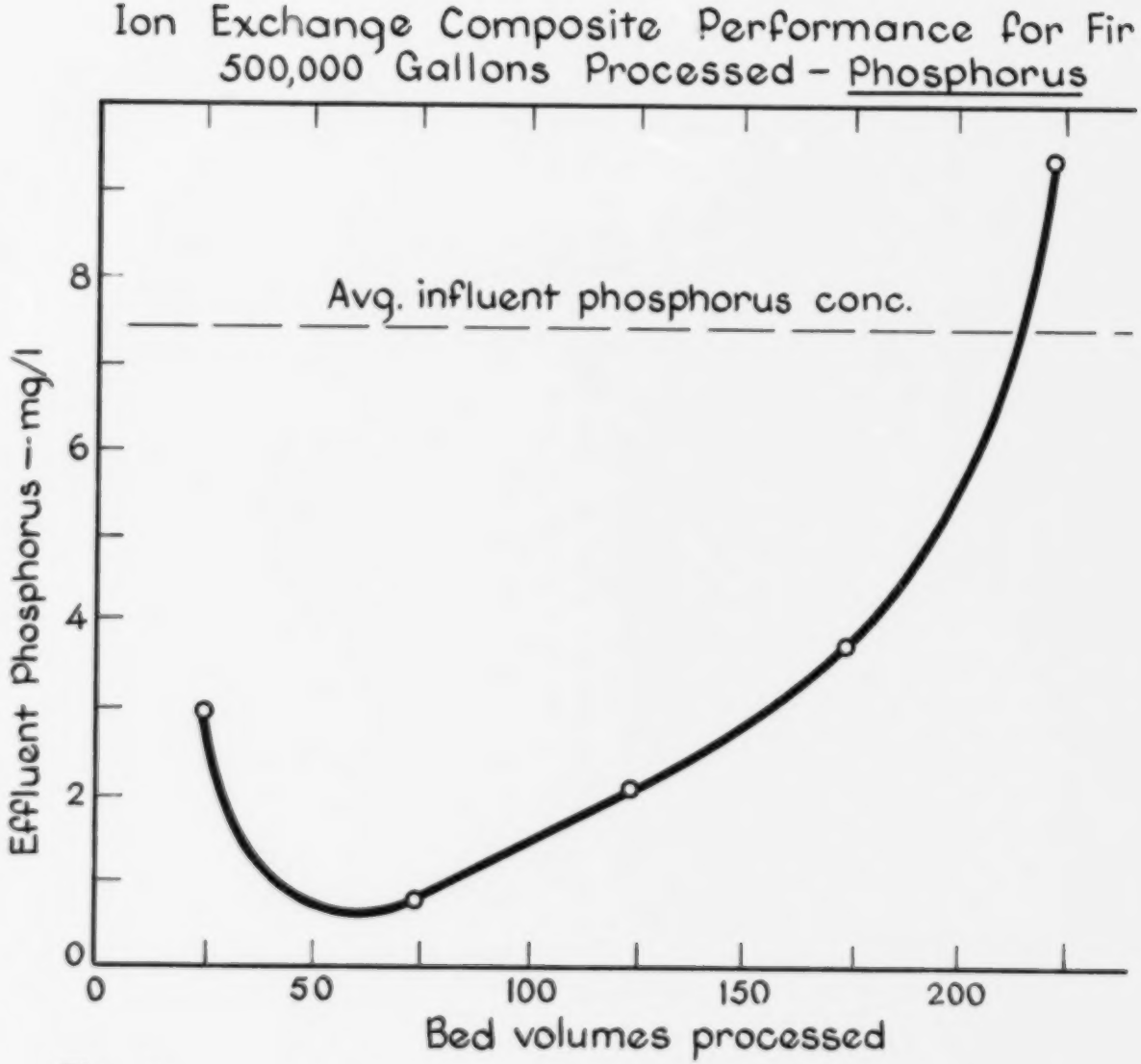

Ion Exchange Composite Performance for Fir
500,000 Gallons Processed - Phosphorus
Avg. influent phosphorus conc.
Effluent Phosphorus — mg/l
0
2
4
6
8
0
50
100
150
200
Bed volumes processed

Fig. 3

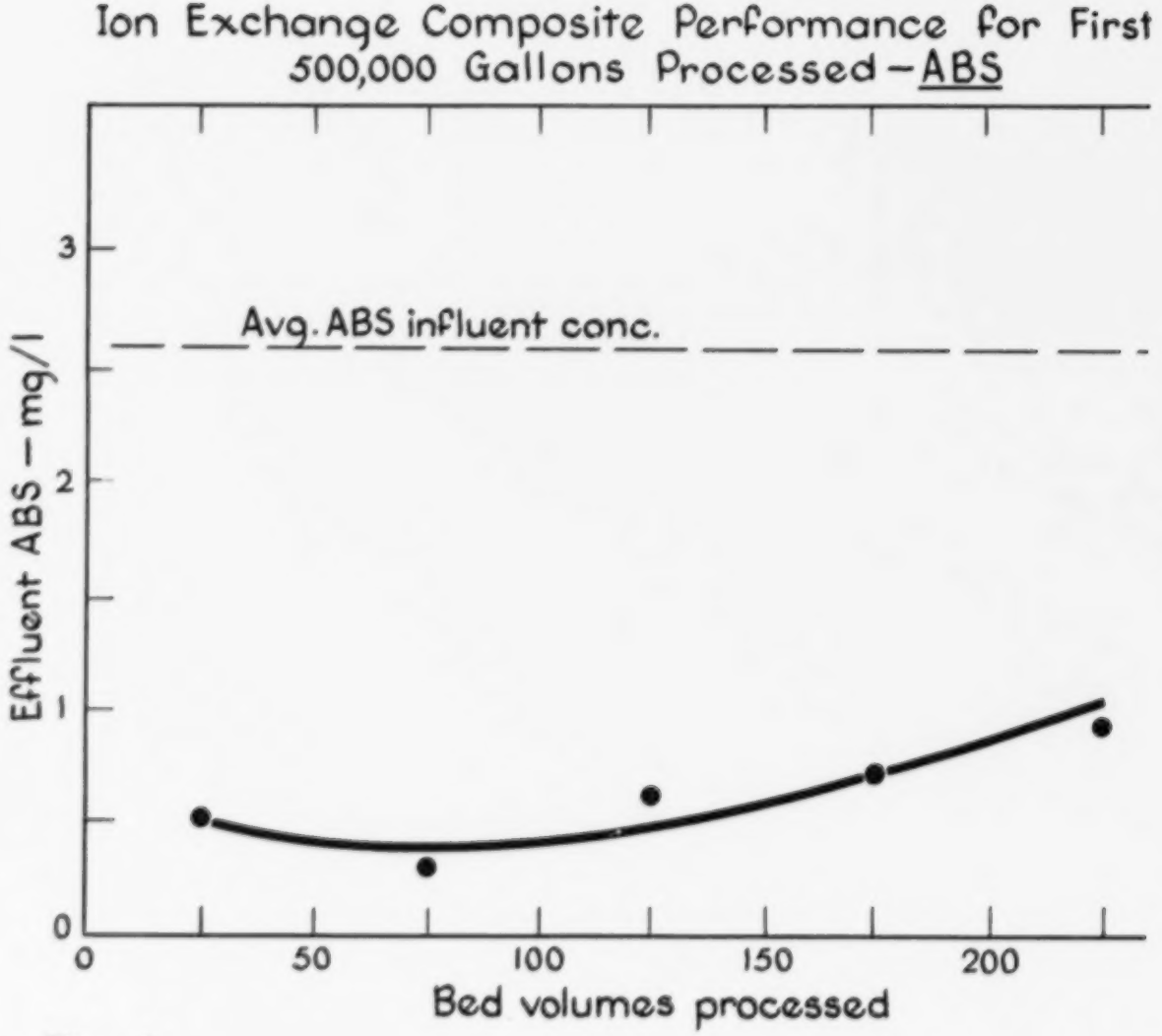

Ion Exchange Composite Performance for First 500,000 Gallons Processed – ABS
Avg. ABS influent conc.
Effluent ABS – mg/l
0
1
2
3
0
50
100
150
200
Bed volumes processed

Fig. 4

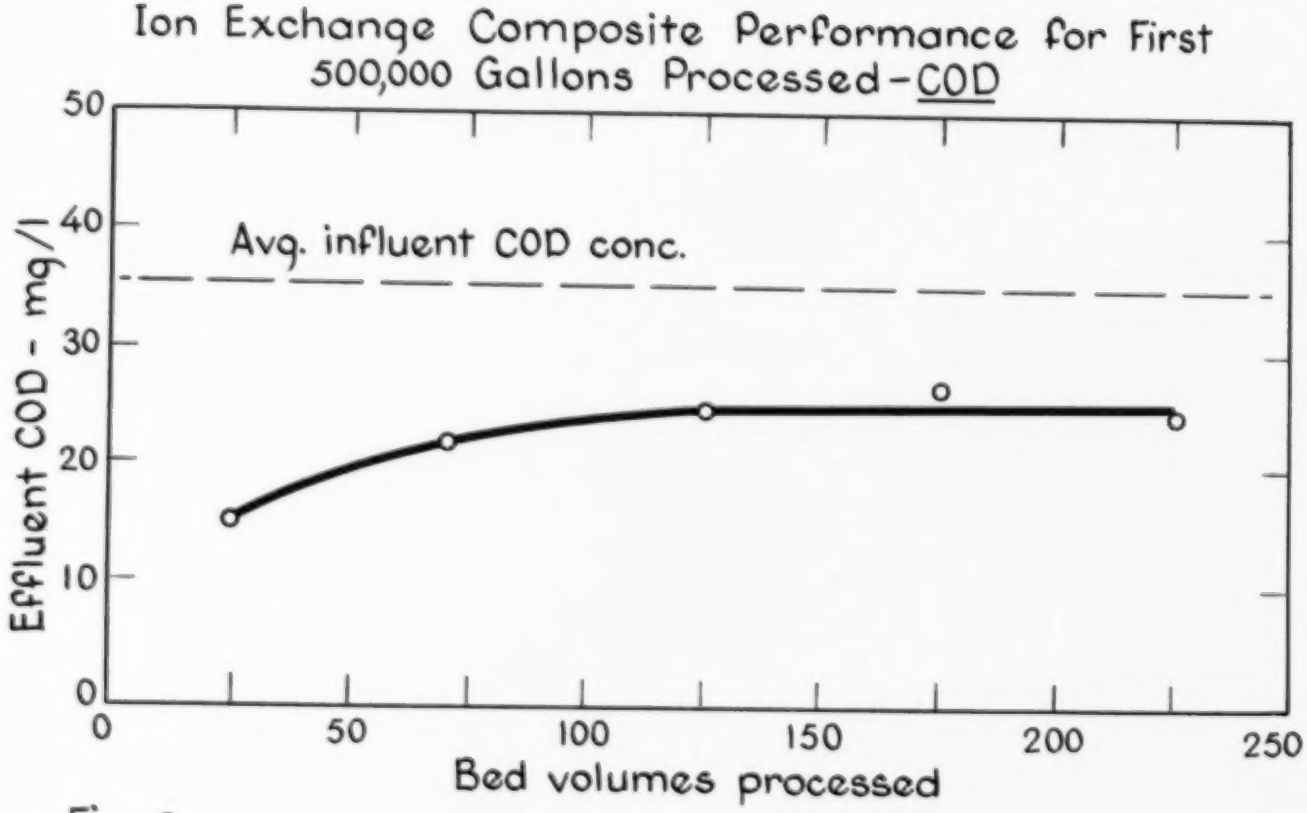

Ion Exchange Composite Performance for First
500,000 Gallons Processed - COD
Avg. influent COD conc.
Effluent COD - mg/l
0
10
20
30
40
50
0
50
100
150
200
250
Bed volumes processed

Fig. 5

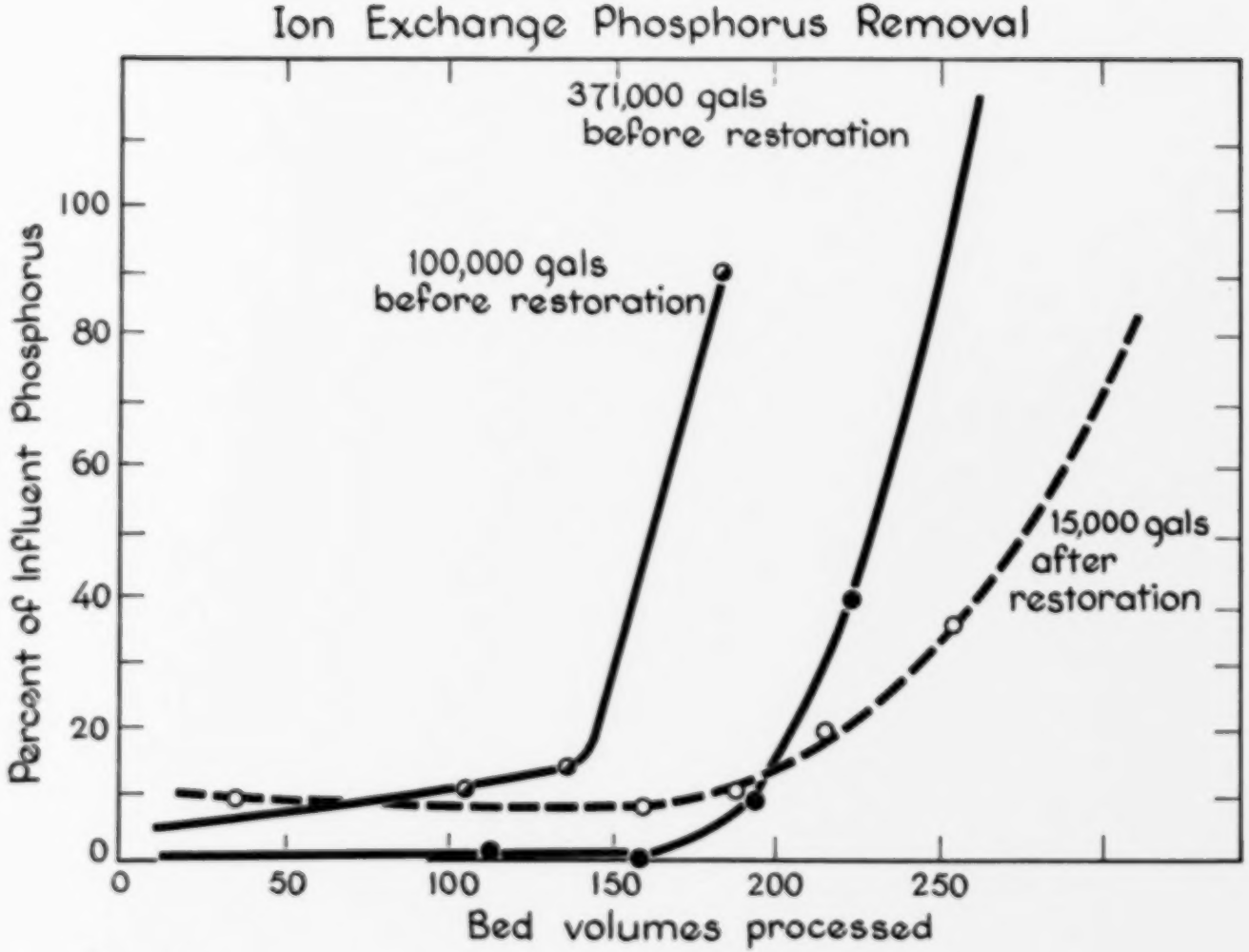

Ion Exchange Phosphorus Removal
371,000 gals
before restoration
100,000 gals
before restoration
15,000 gals
after
restoration
Percent of Influent Phosphorus
0
20
40
60
80
100
0
50
100
150
200
250
Bed volumes processed

Fig. 6

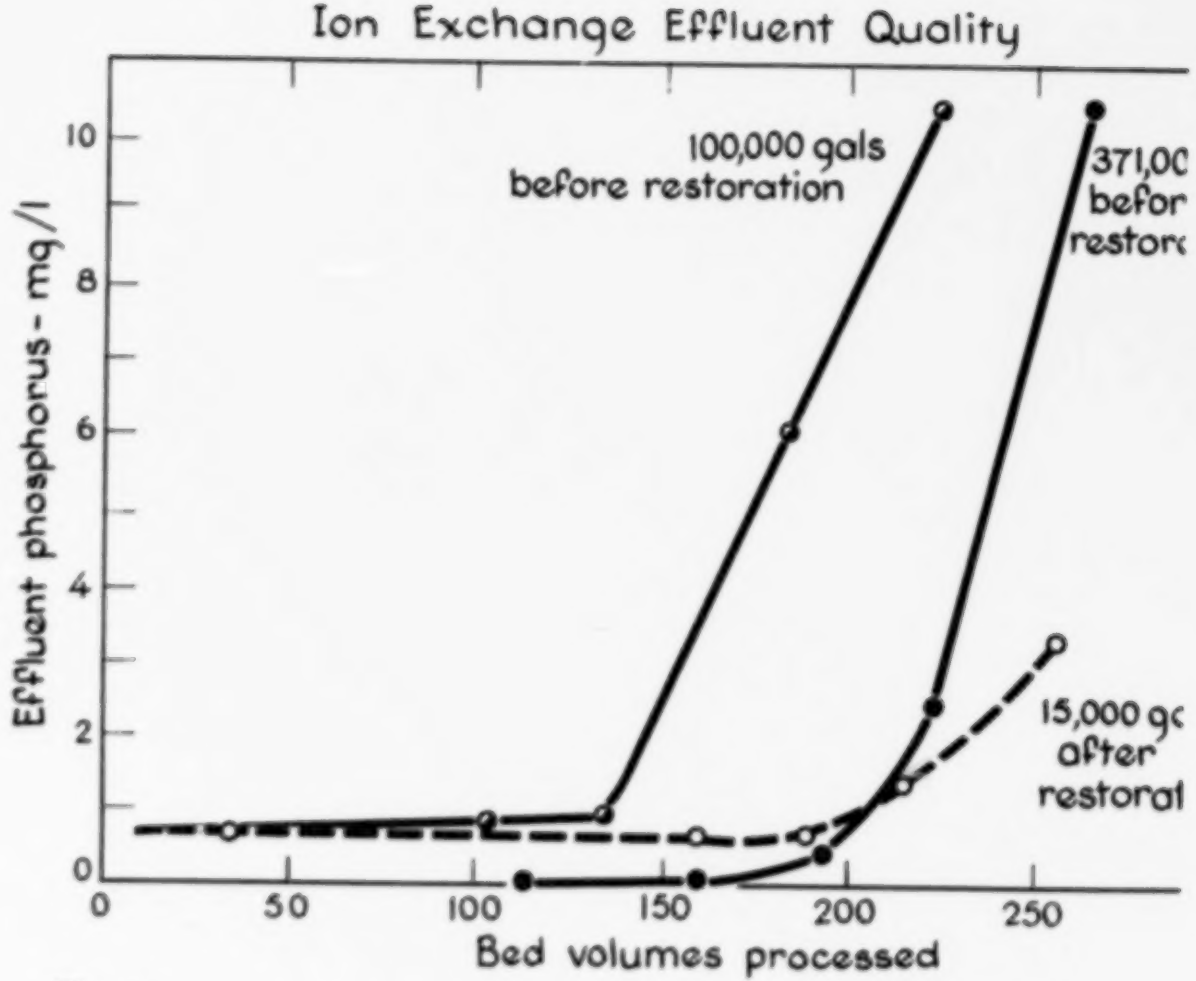

Ion Exchange Effluent Quality
Effluent phosphorus - mg/l
0
2
4
6
8
10
0
50
100
150
200
250
Bed volumes processed
100,000 gals
before restoration
371,0C
befor
restor
15,000 gc
after
restoral

Fig. 7

The final effluent from the ion exchange unit showed about a 25 percent reduction in CCE and a 50 percent reduction of CAE (as compared to the sand filter effluent)."

After 500,000 gallons of effluent had been processed using the ion exchange flow sheet, a field restoration of the resin was performed using the acid-methanol treatment. Laboratory results have indicated that about 850,000 gallons (14,200 B.V.) could be processed between restoration treatments. It was decided to restore the resin somewhat sooner in this case for two reasons. First, because the resin had been subjected to extreme loading conditions in that the quality of the pre-treatment was questionable at times. Secondly, it was deemed wise to develop a practical field technique for resin restoration as early in the testing program as possible, since restoration requires the use of the hydrochloric-acid mixture at a temperature of 43° C. The proposed techniques proved workable, and the resin was successfully restored, as indicated by Figure 6 and Figure 7 and by Table XII. Field restoration results compared favorably with laboratory experience.

In view of the results obtained during this initial trial under somewhat adverse conditions, it appears that operating efficiencies and results comparable to laboratory results should be obtained in the future, provided proper pre-filtration can be provided on a reliable basis.

Economic Study

A study of the economics of Ion Exchange treatment was made by Dr. Rolf Eliassen, Mr. Bruce Wycoff, and Mr. Charles Tomkin. It was concluded that the cost of tertiary treatment using an ion exchange flow sheet similar to that being tested under the present Public Health Service Grant would be on the order of twenty cents per 1,000 gallons, when the input liquid was activated sludge treatment effluent. The complete economic analysis has been included in the appendix of this report.

TABLE XII

TREATMENT EFFICIENCIES*

Last 200,000 Gallons Processed Immediately Before Restoration

	Phosphorous (mg/l)	ABS (mg/l)	COD (mg/l)	Chloride (mg/l)
Average Influent	7.45	2.6	32	234
Average Effluent	2.55	0.63	22	317
Percent Reduction	66%	76%	31%	+36%

First 75,000 Gallons Processed After Restoration

	Phosphorous (mg/l)	ABS (mg/l)	COD (mg/l)	Chloride (mg/l)
Average Influent	7.0	1.12	24	200
Average Effluent	0.8	0.28	16	339
Percent Reduction	88.5%	75%	33%	+70%

* For first 200 BV of each run.

FUTURE OBJECTIVES

Objectives in the immediate future will be as follows:

1. To perfect full-scale filtration techniques capable of rendering activated sludge effluent waters suitable for treatment by ion exchange and other tertiary treatment techniques.

2. To determine the operating efficiency and performance characteristics of an ion exchange treatment, utilizing pre-filtration and regular resin regneration up to a total volume of 825,000 gallons (14,200 B.V.).

3. To determine the effectiveness of resin restoration (after 14,200 B.V.) under actual field operating conditions.

4. To determine the degree of algae inhibition relative to the phosphorous removal efficiency of ion exchange treatment.

5. To confirm the operating assumptions and performance predictions utilized in preliminary economic feasibility analyses.

PROFESSIONAL STAFF

1. Project Director - Dr. Rolf Eliassen, Professor of Sanitary Engineering, Stanford University.

   Professor Eliassen has been with the project since its inception and has spent about 10 percent of his time on the project. Biographical data were included in the original application.

2. Dr. Perry L. McCarty, Associate Professor of Civil Engineering, Stanford University.

   Professor McCarty has been with the project since its inception and has spent about 10 percent of his time on the project. Biographical data were included in the original application.

3. Bruce M. Wyckoff, Civil Engineer, Jenks and Adamson Co.

   Mr. Wyckoff was with the project for 100 percent of his time from October 15, 1962 until August 31, 1964 and has spent 10 percent of his time since then on the project. Biographical data were included in the progress report dated August 9, 1963.

4. George E. Bennett, Research Engineer, Stanford University.

   Mr. Bennett joined the project on August 23, 1965 and has spent 100 percent of his time on the project.

   Education: B.S. in Civil Engineering, 1957, State University of Iowa.

   M.S. in Sanitary Engineering, 1962, Massachusetts Institute of Technology.

   Registered Civil Engineer: Kentucky
   Registered Sanitary Engineer: Iowa

Experience: Research Engineer, 1962-1965, Water Management Laboratory, General Electric Co., Louisville, Kentucky.

Sanitary Engineer, U. S. Air Force, 1958-1961, Loring Air Force Base, Maine, and Ramstein Air Base, Germany.

Field Engineer, 1957-1958, Chicago Pump Company, Chicago, Illinois.

Operator, 1956-57, Oakdale Sewage Treatment Plant, Oakdale, Iowa.

Operator, 1955-56, University Water Plant, Iowa City, Iowa.

REPORTS AND ARTICLES

In June of 1965, a paper entitled "Ion Exchange for Reclamation of Reusable Water Supplies," was presented by Dr. Rolf Eliassen at the 1965 Conference of the American Water Works Association. It was published in the Journal of that organization, Vol. 57, p. 1113-1122, September 1965 under the authorship of Eliassen, Wyckoff, and Tonkin.

ACKNOWLEDGEMENTS

This project has been financed by a Demonstration Grant (WPD-21-03-64) from the Division of Water Supply and Pollution Control of the U. S. Public Health Service. The City of Palo Alto has cooperated in site preparation and pilot plant construction and operation.

The bulk of the work covered in this report was performed under the direction of Charles D. Tonkin, who served as Director of the Demonstration Plant until September 13, 1965. Operating data for the activated sludge unit were collected and analyzed by Ray Morales, who was at the time a student in Sanitary Engineering and a candidate for the degree of Engineer.

The comminutor and the "Rapid Bloc" activated sludge plant were donated by the Chicago Pump Co. The chemical treatment unit which combines mixing, coagulation and sedimentation, lime and alum feeders, and the rapid sand filter were donated to the project by Infilco, Inc. The diatomaceous earth filter was provided by DeLaval Turbine, Inc. Following the filters is an ion exchange unit provided by Infilco. BIF Industries donated a chemical feeder and the Worthington Corp. donated a pump. All chemicals for use in the project, with the exception of the laboratory chemicals, were supplied by Stauffer Chemical Company, and Kaiser Industries. Diamond Alkali Co. provided ion exchange resins; Dow Chemical Co. and Pittsburgh Chemical Co. also provided some treatment materials. Johns-Manville provided diatomaceous earth; and Leslie Salt Co. donated salt for regeneration of the resins. Infilco, DeLaval, and Diamond Alkali were also helpful in providing data for the economic studies. The cooperation of these firms is gratefully acknowledge. Gratitude is also expressed to Jerome Keithley, City Manager, Harold L. May, Director of Water and Sewers, and Ludwig Huebner, Superintendent of the Sewage Treatment Plant, all of the City of Palo Alto, and many of the City's personnel for their part in this project.

APPENDIX

ECONOMICS OF ION EXCHANGE

Certain assumptions must be made in order to assign a cost to the ion exchange process for tertiary treatment of waste waters. Results of laboratory studies were used to predict resin performance. The average length of run was assumed to be 175 bed volumes. This makes an allowance for shorter runs due to resin clogging between restoration treatments. For the same reason, an intermediate resin removal performance was used. Table II presents the estimated initial concentrations of the ion exchange process treating diatomaceous earth filtered activated sludge effluent.

TABLE II

ANALYTICAL BASES FOR COST ANALYSES OF ION EXCHANGE PROCESS

Analysis	Initial Concentration (mg/l)	Effluent Concentration (mg/l)	Percent Removal
Phosphate (as P)	8	0.4	95
Nitrogen (as N)	18	2.9	84
Sulfates	65	0	100
Chlorides	200	360	-180
ABS	2.0	0.28	86
COD	35	19	46
Color (units)	38	19	49

It was assumed that bentonite treatment would be performed after each 3,000 bed volumes of flow to keep the resin in good condition. A restoration treatment after each 14,200 bed volumes was figured with sodium hydroxide and acid-methanol used alternately. Resin life was assumed to be two million gallons per cubic foot which would mean that the resin could receive 19 restorations before it would have to be replaced.

Plant costs have been developed using diatomaceous earth (D.E.) filtration with automatic operation. The ion exchange equipment itself should be capable of semi-automatic operation. All reasonable costs have been accounted for, including an administration building, chemical storage, chlorination equipment, paving and fencing, engineering costs, miscellaneous costs and a nominal land cost. Annual cost was developed using an interest rate of 3.5 percent and a 20-year equipment life based on total plant cost of $475,000.

The capacity of the plant has been assumed to be 3 Mgd. Six ion exchange columns have been used, with only five necessary to produce the required quantity of water. The idle column would undergo regeneration and restoration treatments. Two D.E. filters were included, with each unit capable of producing 3 Mgd on a temporary overload basis. A high degree of reliability would be assured.

Twenty-four hour operator supervision was assumed with one full time director and a liberal allowance for overhead. Current construction costs in the Palo Alto, California area were assumed. Power cost was estimated at 1.5 cents per kilowatt-hour. Table III presents the summary of costs.

TABLE III

TOTAL COSTS OF TERTIARY TREATMENT
BY DIATOMACEOUS EARTH AND ION EXCHANGE

Item	Costs-Cents/1000 Gal.
Resin replacement	2.75
Salt	3.58
Bentonite	0.10
Methanol	2.50
Hydrochloric acid	0.13
Sodium hydroxide	0.09
Diatomaceous earth	0.52
Sub-total:	9.67
Labor, supervision and overhead	6.60
Power	1.43
Capital recovery costs	3.05
Total:	20.75

Chlorination for disinfection would add about 0.3 cents to the cost if disinfection were required to the extent of 5 mg/l of chlorine. Waste disposal costs have not been included. At Palo Alto, spent brine would be disposed of to the bay. Wash water could be returned to the sewage treatment plant.

The calculated total costs of 20.75 cents per 1000 gallons for tertiary treatment of an effluent from a secondary waste treatment plant may be compared with the price of 21.5 cents per 1000 gallons which the City of Palo Alto is currently paying for unfiltered

Hetch Hetchy water supplied by the City of San Francisco. This amounts to $70 per acre/foot. Since secondary treatment of municipal waste waters is usually required in most localities, only the cost of tertiary treatment has been included as an added factor in the reclamation of water for further community use.